Electron-Phonon Interaction in Silver

Tai C. Chiang, U of Illinois at Urbana-Champaign, DMR-0203003

A metal consists of atoms that naturally vibrate. Such vibrations form sound waves that are quantized and the associated energy quanta are known as phonons. Electrons in a metal can interact with phonons, resulting in a host of interesting and important phenomena including superconductivity. Few techniques allow direct determination of electron-phonon interaction. This experiment successfully overcomes the usual limitations by using highly smooth thin films instead of a bulk crystal. Electrons trapped in the films form discrete states (known as quantum well states) much like the states in an atom or a molecule. Photoemission spectroscopy studies of quantum well states using synchrotron radiation yield the first result for silver.

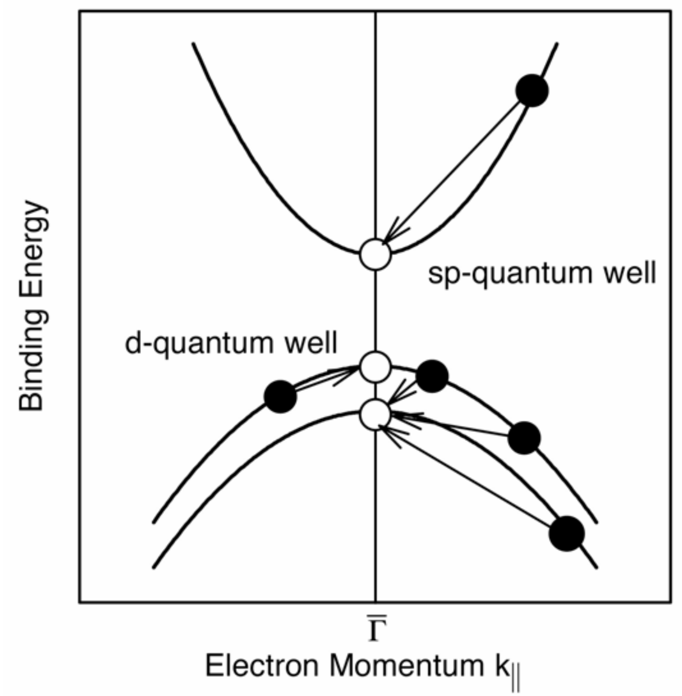

Diagram illustrating the decay processes for various quantum well states caused by phonon scattering. The differences in available decay channels result in substantial differences in the electron-phonon interaction strength.

Phys. Rev. Lett. **92**, 186803 (2004).

A metal consists of atoms that naturally vibrate. Such vibrations form sound waves that are quantized, and the associated energy quanta are known as phonons (just as photons are energy quanta associated with light waves based on Einstein's theory of special relativity). Electrons in a metal can interact with phonons, resulting in a host of interesting and important phenomena including electrical resistivity and superconductivity. The connection to electrical resistivity is easy to see, as electrons in motion can be scattered off course by phonons, effectively hindering the electron motion. By contrast, the connection to superconductivity is subtle, but is well explained by the Nobel-prize-winning theory of Bardeen, Cooper, and Schrieffer (the BCS theory). In essence, a strong electron-phonon interaction can cause a high electrical resistivity in ordinary metals, but in superconductors, perhaps paradoxically, the strong interaction causes the electrons to pair up to form Cooper pairs that actually conduct without resistance.

A high superconducting transition temperature is of great scientific and technological interest, which drives a need to understand electron-phonon interaction. Accurate and detailed measurements of electron-phonon interaction are thus important, but few techniques allow a direct determination. This experiment successfully overcomes the usual limitations by using thin films instead of a bulk crystal, and the idea is tested out for silver (Ag), a common metal widely used for industrial and electronic applications. A very difficult prerequisite, which this group of researchers has been able to achieve, is to prepare the films with atomic layer perfection. Electrons trapped in such films form discrete states (known as quantum well states) much like the states in an atom or a molecule. In a sense, the films are like artificial atoms or molecules with adjustable sizes. Experimentally, synchrotron radiation is used to probe the discrete states in the films. As the system temperature is raised, the atoms vibrate more vigorously, and the scattering rate by phonons increases. From the measured rate increase, the electron-phonon interaction is determined. The results show, for the first time, drastically different electron-phonon interactions for different electronic states. This detailed information is crucial for further developing a microscopic understanding for the electron-phonon interaction. The results also have interesting implications regarding how one might modify the material configurations to achieve a higher superconducting transition temperature.

Publication: J. J. Paggel, D.-A. Luh, T. Miller, and T.-C. Chiang, Electronic structure dependence of the electron-phonon interaction in Ag, Phys. Rev. Lett. **92**, 186803 (2004).

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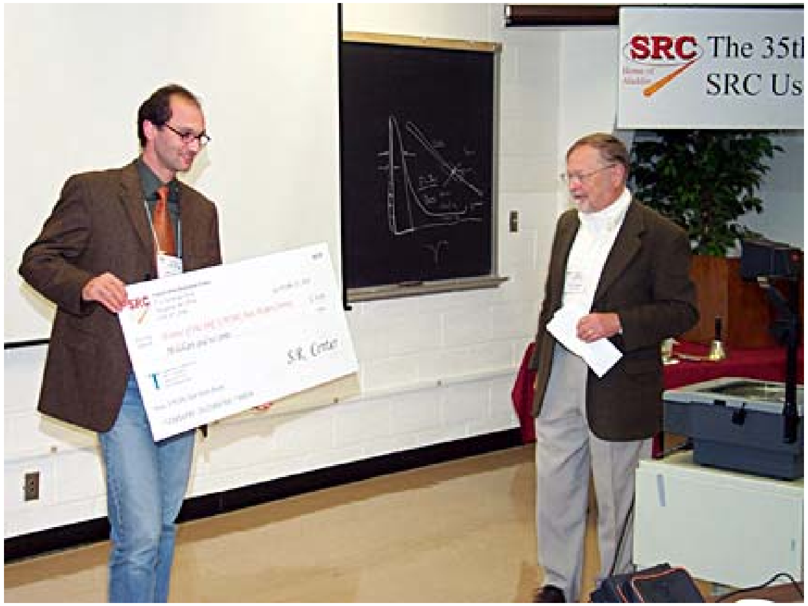

Jens Paggel from the Freie University in Berlin (left) received a best-poster prize at the 35th SRC User's Meeting for his work on silver films grown on iron substrates. These films act as quantum wells, and an angle-resolved photoemission study yields a detailed understanding of the electron-phonon coupling in silver. Standing on the right is Dave Lynch of the Ames Laboratory.

Education:

This program involves graduate student Mary Upton, postdoctoral scholars Shu-Jung Tang and Dah-An Luh, research faculty member Tom Mille, and visiting professor Jens Paggel from the Freie University. The work is performed at the Synchrotron Radiation Center, which is supported by the National Science Foundation (DMR-0084402).

Societal Impact:

This study shows, for the first time, drastically different electron-phonon interactions for different electronic states. This detailed information is crucial for further developing a microscopic understanding for the electron-phonon interaction. The results also have interesting implications regarding how one might modify the material configurations to achieve a higher superconducting transition temperature.